

PATENT SPECIFICATION

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(54) LIQUID CRYSTAL DEVICES

(71) I, SECRETARY OF STATE FOR DEFENCE, London, do hereby declare the invention for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates generally to a liquid crystal device and particularly to such a device having an electrically tunable optical activity.

According to the present invention a liquid crystal device includes a liquid crystal cell located between two polarisers, the cell comprising a layer of cholesteric liquid crystal material between first and second optically transparent and electrically insulating substrates having on the inner surfaces thereof first and second optically transparent electrodes respectively, and wherein said cell the molecules of the liquid crystal material immediately adjacent said first electrode lie with their axes on average perpendicular or approximately perpendicular to the surface of said first electrode, and the molecules of the liquid crystal material immediately adjacent said second electrode lie with their axes on average unidirectionally aligned and at an angle between 0° and 35° inclusive to the surface of said second electrode, and wherein the helical pitch of the molecular arrangement in the liquid crystal material is such that in use the amount by which the plane of polarisation of optical radiation traversing the cell is rotated may be changed upon application of an electric field between respective electrodes.

"Optical radiation" is intended to include radiation in the infra-red and ultra-violet parts of the electromagnetic spectrum in addition to radiation in the visible part.

The first and second substrates are both made of optically transparent electrically insulating material preferably glass. The electrodes are both made of optically transparent electrically conducting material preferably tin oxide, or indium oxide, located on the inner surfaces of said first and second substrates. The electrodes may be patterned in the form

of one or more characters or figures to form a display, e.g. an alphanumeric display.

The surfaces of the electrodes may be treated in known manner, each to give the required liquid crystal molecule alignment. For example, and in the case of electrodes of tin oxide or indium oxide, the surface of the first electrode may be previously coated with a substance such as organo-silane, or it may be cleared with detergent to cause liquid crystal molecules to lie perpendicularly to the surface. The surface of the second electrode may be previously treated in any of the ways known to cause liquid crystal molecules to lie parallel or obliquely to (with an angle of not more than 35°) the surface, such as by rubbing the surface with a soft tissue in a single direction or by evaporating molecules of a dielectric material such as magnesium fluoride on the electrode at an oblique angle to the surface.

The cholesteric liquid crystal material may be one of the following:

- A mixture of cholesterogenic material and nematogenic material; or
- A mixture of non-liquid crystal optically active material and nematogenic material.

Preferably the material has a positive dielectric anisotropy although it may have a negative dielectric anisotropy.

Preferably the optical polariser located in front of the second substrate is arranged to polarise radiation incident on the second substrate parallel to the average projection on the said second surface of the liquid crystal molecules immediately adjacent to that surface. An optical polarisation analyser (i.e. the other polariser) is located behind the first substrate. If an electric field is applied across the layer of liquid crystal material, or if an electric field already applied is changed or removed, the amount by which the plane of polarisation of the radiation is rotated on passing through the layer in the region where the electric field change occurs is correspondingly changed. Hence the intensity of

radiation passed through the analyser from this region is changed. The nature of the change may be an increase or a decrease in intensity or an increase followed by a decrease or a decrease followed by an increase or a combination of increases and decreases depending on (a) the polarisation axis of the analyser (b) the helical pitch of the liquid crystal molecular arrangement, (c) the nature and magnitude of the change in applied electric field and (d) the dielectric anisotropy of the liquid crystal material. Preferably, the helical pitch, is a 2π turn in the helix of the molecular arrangement, is in the order of or greater than the average thickness of the layer.

In a second form of the invention one or more layers of a birefringent material such as Cellophane (Registered Trade Mark) may be inserted between the first substrate and the analyser or between the second substrate and the polariser. The device then behaves similarly to the known device which comprises a layer of birefringent material and a twisted nematic liquid crystal cell both located between a polariser and an analyser, in that when a change, which may be from zero, is made in the electric field applied across a region of the layer of liquid crystal material the colour of light passed through the corresponding region of the analyser is correspondingly changed.

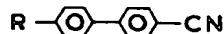
Embodiments of the present invention will now be described by way of example with reference to the drawings filed with the provisional specification, in which:

Figure 1 is a schematic cross-sectional diagram of an electro-optic shutter;

Figure 2 is a schematic cross-sectional diagram of an electrically tunable colour filter constituting a modification of the shutter illustrated in Figure 1;

Figures 3 and 4 are schematic representations, respectively without and with an electric field of the arrangement of positive dielectric liquid crystal molecules in the devices illustrated in Figure 1 and Figure 2.

The electro-optic shutter illustrated in Figure 1 comprises a liquid crystal cell 1, located between a polariser 3 and an analyser 5. The cell 1 comprises a glass side 7 having a surface coating 9 of electrically conducting material such as tin oxide facing a glass slide 11 having a surface coating 13 with a layer 15 of optically active liquid crystal material between the coatings 9 and 13. The material may for instance be a mixture of



where R is an n-alkyl or n-alkoxy group such as $n\text{-C}_{11}\text{H}_{23}$, with about 0.4% by weight of a cholesteric material such as cholesteryl nonanoate. A voltage source V providing a

changeable output is connected between the coating 9 and the coating 13.

The surface of the coating 9 has previously been rubbed in a single direction with a soft tissue so that the liquid crystal molecules immediately adjacent to the coating 9 lie roughly along the rubbing direction. The surface of the coating 13 has previously been treated with silane so that the liquid crystal molecules immediately adjacent to the coating 13 lie substantially perpendicular to the coating 13.

The polarising axis of the polariser 3 is here arranged to be parallel to the rubbing direction on the slide 7. The polarising axis of the analyser 5 may be arranged to be at some acute angle to that of the polariser 3. The voltage from the source V is adjusted until the helical twist of the molecular arrangement in the layer 15 is such as to give minimum transmission of light from a fixed intensity white light source S located in front of the polariser 3. By adjusting the voltage the transmission through the analyser 5 increases, because the molecular arrangement is changed, causing the number of helical twists or fraction of a twist, occupied by the molecular arrangement, to be changed. This increase in voltage may be in the form of a pulse which returns rapidly to the value of voltage required to give minimum transmission, so that the light transmitted through the analyser 5 is in the form of a pulse. One explanation is given below for the possible way in which the molecular arrangement in layer 15 is changed by the voltage.

The colour filter illustrated in Figure 2 is constructed in the same way as the shutter illustrated in Figure 1; however the colour filter additionally includes a sheet 17 of birefringent material such as Cellophane (Registered Trade Mark) between the cell 1 and the analyser 5 with the optic axis of the sheet 17 preferably at an angle of 45° to the polarising axis of the analyser 5. The structure acts as a colour filter by strongly transmitting through the analyser 5 light of a particular colour which depends on the thickness of the sheet 17. By changing the voltage from the source V the colour strongly transmitted is changed. The output voltage provided by the voltage source V may be constantly varying; for example it may be derived from the output of a radio receiver or of a record player so that automatic and continuous modulation of colour is obtained coinciding with the modulation in sound.

In practice the polariser 3, the analyser 5, the sheet 17 and the cell 1 may form a composite structure.

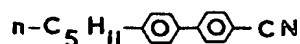
One possible simplified explanation of the way in which the change in liquid crystal molecular arrangement occurs in the devices illustrated in Figures 1 and 2 is as follows. Figure 3 illustrates the arrangement of

molecules M through the layer 15, in the plane containing the rubbing direction on the coating 9, with no applied voltage. The molecules M are in helical arrangement throughout a thickness T_1 of the layer 15 as measured from the coating 9: this is illustrated by the feature that their projection on the plane becomes very small at a place S where they lie perpendicularly to the rubbing direction, but in a plane which is parallel to the plane of the coating 9. After the thickness T_1 the molecules M tip over to become perpendicular to the coating 13.

The effect of applying a voltage across the layer 15 is, to cause more molecules M adjacent to the coating 13 to tip over to become perpendicular to the coating 13 provided that the material has a positive dielectric anisotropy. This causes the thickness of the helical arrangement to be reduced to a value T_2 as illustrated in Figure 4. Hence, the optical activity, i.e. the so-called specific optical rotation, provided by the layer 15 is reduced.

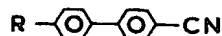
The advantage of this effect, for the configuration described is that the optical activity or specific optical rotation change induced in the layer 15 by the applied voltage is not associated with birefringence effects because the optic axis of the layer 15 is perpendicular to the coating 13. As a result light polarised linearly by the polariser 3 is not converted into elliptically polarised light as it is in most known devices employing voltage controlled optical activity effects; instead the light remains linearly polarised when it emerges from the coating 13 and this gives more adjustability over its intensity or colour as appropriate.

A device of the kind illustrated in Figure 1 having a 12 μm thick layer of



mixed with 0.2% by weight of cholesteryl nonanoate has been made with one glass slide rubbed to give roughly parallel alignment of the liquid crystal molecules and the other slide cleaned with detergent to give perpendicular alignment of the molecules. Using a 50 Hz voltage signal varying between 0 and 1.6 V rms it has been found that the angular helical twist in the liquid crystal material varies smoothly from 43° to 0° .

Materials made from compounds having the composition



have a positive dielectric anisotropy. Materials made from compounds such as para - methoxy - benzylidene - butyl - aniline (MBBA) have a negative dielectric anisotropy.

Materials having a negative dielectric anisotropy may be used in the devices illustrated in Figures 1 and 2 but the applied voltage must be relatively high and have a frequency above the ionic relaxation frequency of the material. In this case the thickness of the helical twist region in the liquid crystal molecular arrangement is increased by an increase in voltage.

In another embodiment of the invention the layer 15 may be replaced by a wedge-shaped layer so that one region of the wedge appears dark (i.e. gives minimum transmission) with no voltage applied. As a voltage is applied and gradually increased, the dark region is observed to move laterally across the analyser.

WHAT I CLAIM IS:—

1. A liquid crystal device including a liquid crystal cell located between two polarisers, the cell comprising a layer of cholesteric liquid crystal material between first and second optically transparent and electrically insulating substrates having on the inner surfaces thereof first and second optically transparent electrodes respectively, and wherein said cell the molecules of the liquid crystal material immediately adjacent said first electrode lie with their axes on average perpendicular or approximately perpendicular to the surface of said first electrode, and the molecules of the liquid crystal material immediately adjacent said second electrode lie with their axes on average unidirectionally aligned and at an angle between 0° and 35° inclusive to the surface of said second electrode, and wherein the helical pitch of the molecular arrangement in the liquid crystal material is such that in use the amount by which the plane of polarisation of optical radiation traversing the cell is rotated may be changed upon application of an electric field between respective electrodes.

2. A device as claimed in claim 1 wherein the polariser adjacent said second substrate is arranged such that its axis of polarisation is substantially parallel to the projection on the surface of said second electrode of the average direction of the axes of liquid crystal molecules immediately adjacent thereto.

3. A device as claimed in claim 1 or claim 2 and wherein the first and second substrates are made of glass and the electrodes are made of tin oxide or indium oxide, the surfaces of the electrodes each being treated to give the required liquid crystal molecule alignment.

4. A device as claimed in any one of the preceding claims and wherein the electrodes are part of an electrode pattern defining one or more display characters or figures.

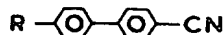
5. A device as claimed in any one of the preceding claims and wherein the device additionally includes one or more layers of a

solid birefringent material located between the polarisers.

5 6. A device as claimed in any one of the preceding claims and wherein the cholesteric liquid crystal material has a molecular helical pitch of the order of or greater than the average thickness of the layer of liquid crystal material.

10 7. A device as claimed in any one of the preceding claims and wherein the first and second substrates are mutually arranged so that the separation between said inner surfaces varies in a wedge shaped fashion, whereby application of an electric field of
15 varying magnitude between the respective electrodes on the first and second surfaces is capable of moving a distinctive localised optical property device along the wedge.

20 8. A device as claimed in any one of the preceding claims and wherein the liquid crystal material is a mixture of a compound having the formula



25 where R is an n-alkyl or n-alkoxy group, and an optically active material.

9. A device as claimed in claim 8 and wherein the optically active material is a cholesterogenic liquid crystal material.

10. A device as claimed in claim 8 and wherein the optically active material is a non-liquid crystal material. 30

11. A liquid crystal device as claimed in any one of the preceding claims and wherein the first substrate has been treated in one of the ways described hereinbefore to provide alignment of the liquid crystal molecules perpendicular or approximately perpendicular to the first surface and the second substrate has been treated in one of the ways described hereinbefore to provide alignment of the liquid crystal molecules at an angle between 0° and 35° inclusive to the surface of said second electrode. 35 40

12. A liquid crystal device substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the drawings filed with the Provisional Specification. 45

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